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Disentangling the relative influence of built and socioeconomic environments on walking: The contribution of areas homogenous along exposures of interest

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Abstract

The geography of small areas has important implications for studying the contextual determinants of health because of potential errors when measuring ecologic exposures and estimating their effects on health. In this paper, we present an approach for designing homogeneous zones optimising the spatial distribution of an area-level exposure, active living potential (ALP), based on data collected in Montreal, Canada. The objectives are to (1) assess and compare variation in walking behaviours between these purposefully designed zones and between standard administrative units, census tracts; and (2) disentangle the relative influence of ALP and area-level socioeconomic conditions on walking using the alternative geographies. Zones were designed by statistically classifying smallest census areas (disseminations areas) into seven categories of exposure similar along three indicators of ALP: population density, land use mix, and geographic accessibility to services. Mapping of categories resulted in the delineation of zones characterised by one of seven levels of ALP. A sample of 2716 adults aged ≥45 years was geocoded and cross-classified in 270 zones and 112 census tracts. Individuals reported on minutes and motives of walking and provided socioeconomic information. Data were analysed using cross-classified multilevel models. Variation in utilitarian walking was larger across the purposefully defined zones than across census tracts. Total walking varied significantly between census tracts only. Greater ALP was associated with more utilitarian walking but with less recreational walking. Higher socioeconomic position in census tracts was positively associated with total, utilitarian, and recreational walking. The soundness of standard administrative units for measuring ecologic exposure and their associations with health should be considered prior to conducting analyses. The added value of different approaches for understanding how place relates to health remains to be established and should be the focus of further investigations.

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Keywords

Canada; Small area analysis; Zone design; Walking; Built environment

Introduction

The geography of small area units has important implications for studying the contextual determinants of health because it is likely to influence the measurement of ecologic exposures (area-level characteristics) and the estimation of their effects on health (Cockings & Martin, 2005; Flowerdew, Manley, & Sabel, 2008; Haynes, Daras, Reading, & Jones, 2007; Haynes, Jones, Reading, Daras, & Emond, 2008; Oliver & Hayes, 2007; Stafford, Duke-Williams, & Shelton, 2008). The prevailing '*one-size fits all*' approach to defining small areas using standard administrative spatial units may therefore be '*too simplistic*' (Stafford et al., 2008). The most appropriate geography may be specific to the epidemiological outcome of interest (Chaix, Rosvall, Lynch, & Merlo, 2006; Cummins, Macintyre, Davidson, & Ellaway, 2005; Galea& Ahern, 2006; Gauvin, Robitaille, Riva, McLaren, Dassa, & Potvin, 2007; Stafford et al., 2008) and should be considered prior to conducting analyses (Flowerdew et al., 2008).

In this paper, we present an approach for designing homogeneous zones optimising the spatial distribution of a specific area-level exposure, active living potential, previously shown to be associated with a specific health indicator, walking. We then assess and compare the extent of variation in walking between these newly designed zones and between standard administrative units, i.e. census tracts, and estimate the relative influence of active living potential and area-level socioeconomic conditions on walking using alternative geographies.

Conceptual and methodological issues related to the operational definition of areas

In research on area effects on health, although the validity and reliability of measures of ecologic exposures are being perfected (Diez-Roux, 2008), defining "appropriate" small area units remains a challenge that gives rise to conceptual and empirical issues potentially challenging the construct and internal validity of studies (Osypuk & Galea, 2007).

Most often, areas are conceptualised as an ecological level of influence within which individuals are exposed to similar contextual conditions. Several authors have developed novel alternative approaches for defining small areas, using such methods as automated zone design (Cockings & Martin, 2005; Flowerdew et al., 2008; Haynes et al., 2007; Stafford et al., 2008) and combination of social, statistical, and spatial analysis methods (Browning & Cagney, 2003; Coulton, Korbin, Chan, & Su, 2001; Lebel, Pampalon, & Villeneuve, 2007; Popay, Thomas, Williams, Bennett, Gattrell, & Bostock, 2003). These efforts are far too few in comparison to studies defining areas using standard administrative units such as census tracts, wards, boroughs, or postcode sectors (Pickett & Pearl, 2001; Riva, Gauvin, & Barnett, 2007). These units are useful because they can easily be linked to data from censuses and other surveys that can be used to derive ecologic exposure measures. As administrative units are often designed to be homogeneous along socioeconomic dimensions, they may be appropriate for operationalising socioeconomic contexts (Ross, Tremblay, & Graham, 2004, p. 892). However, other contextual dimensions may not be optimally defined and measured within these “arbitrary” spatial units. As pointed out by Stafford and colleagues (2008; p. 892) “ as estimates of between-area variation depend on the way that area boundaries are defined, the debate remains as to whether the effects are fully captured by the areas and aggregations used”.

Heterogeneity of exposure within spatial units is problematic because it may lead to errors when measuring exposures and consequent non-differential classification of exposures. Two geographical “problems” are here at play: the modifiable area unit problem and spatial autocorrelation of geographic data. The modifiable areal unit problem refers to the fact that analytical results are sensitive to the definition of spatial units at which data are aggregated (Openshaw, 1984; Openshaw & Taylor, 1979). In other words, area effects may be observed only at certain scales, i.e. scales at which data are collected and aggregated and may vary or be absent when observed at other scales. Imposing arbitrary spatial units on the distribution of ecological exposures may lead to the delimitation of artificial spatial patterns and to errors in the measurement of ecologic exposures. In addition, using standard administrative units assumes that contextual conditions within one area are different from and influence health independently of the conditions of neighbouring areas, when in fact these conditions are autocorrelated (clustered) in space (Cliff & Ord, 1973). The variation of ecologic exposures may thus be smoothed out by the definition of area units used to measure them.

For any area effects to be detected there must be variation in the exposure being studied, i.e., the differences between areas must be maximised (Rothman & Greenland, 1998). If data are collected in contiguous and heterogeneous areas, variations in both characteristics of environments and health outcomes, and their association, may be misestimated. Indeed, stronger area effects on health have been observed in more homogeneous areas (Haynes et al., 2007; Haynes & Gale, 1999). Within-area homogeneity along the contextual conditions under examination therefore appears as important for minimising measurement error of exposures and non-differential exposure misclassification. This is crucial as these may influence the strength of contextual effect on health: effects may not be detected or may be spurious, therefore limiting the precision of research findings for informing public health and public policy actions to tackle social and geographical inequalities in health.

Establishing the homogeneity of small areas in relation to ecologic exposures hypothesised to be associated with health outcomes or health-related behaviour is therefore a major methodological consideration. Indeed, areas maximizing internal homogeneity of exposure while maximizing differences between them may better capture the extent of variation in health attributable to the different contexts wherein people live (Stafford et al., 2008).

Estimating area effects on walking: are census tracts appropriate spatial units?

In health and place research, understanding the environmental determinants of walking is receiving increasing attention. Practiced regularly, i.e. 30–60 min per day on most days of the week, walking translates into significant benefits for health (Haskell et al., 2007; United States Department of Health and Human Services [USDHHS] 1996). Walking is the most common type of physical activity across all age, income, and ethnic groups. As such, promoting regular walking is one strategy to address the public health burden of physical inactivity and weight-related problems (Haskell et al., 2007; Transportation Research Board and Institute of Medicine of the National Academies [TRB & IOM] 2005; USDHHS, 1996; World Cancer Research Fund/ Institute for Cancer Research [WCRF/AICR] 2007).

Characteristics of the built and social environment of residential areas are being documented as important correlates of walking. Several studies report consistent associations between walking and higher residential/population density, proximity to non-residential destinations, greater land use mix, better road network connectivity, presence and accessibility of parks and open spaces, and safety (for a review of evidence, please see Saelens & Handy, 2008; TRB & IOM, 2005). Results of some studies suggest that environment characteristics are differently associated with motives for walking, i.e. utilitarian versus recreational walking (Frank, Engelke, & Schmid, 2003). Studies investigating socioeconomic contextual effects have reported contrasting findings (Fisher, Li, & Michael, 2004; Giles-Corti & Donovan, 2002; Gordon-Larsen, Nelson, & Beam, 2005; Miles, Panton, Jang, & Haymes, 2008; Ross, 2000; Rutt & Coleman, 2005).

Residential areas can thus be thought of as showing different levels of active living potential (ALP) (Gauvin et al., 2005), that is conditions of environments that encourage the likelihood of active living, i.e. integrating physical activity into daily routines, in individuals and populations (Active living research, http://www.activelivingresearch.org). Understanding the aetiological significance of small areas for walking is therefore essential for informing public health actions aiming at creating supportive environments for active living.

In a previous study set on the Island of Montreal, Canada, we assessed whether or not census tracts were appropriate spatial units for measuring the ALP of residential environments and for estimating the association between this exposure and walking behaviours (Riva, Apparicio, Gauvin, & Brodeur, 2008). Census tracts were selected because of extensive use of this spatial unit of analysis in current North American research on health and place. For doing so, we designed zones that were homogeneous along three indicators of ALP, population density, land use mix, and geographic accessibility to selected proximity services. These zones maximised the between-area variation in ALP while minimised within-area variation. The soundness of census tracts for measuring active living potential was assessed by their comparison to zones.

We observed that although census tracts were homogenous along accessibility to services, they were more heterogeneous in terms of population density and land use mix; the variation *within* census tracts along these two indicators was greater than variation *between* census tracts. Furthermore, more than half of census tracts (55.5%) encompassed environments that were substantively different from one another, i.e. environments that were most conducive to walking along others that were least so. In contrast, census tracts were more homogeneous in relation to socioeconomic indicators, which spatial distribution did not coincide with that of ALP indicators. These findings suggest that averaging values of indicators of ALP at the census tract level could potentially lead to significant measurement errors of exposure therefore limiting the soundness of inference about effects of ALP on walking. In addition, processes underlying the distribution of active living and socioeconomic indicators, although possibly linked (Daniel, Moore, & Kestens, 2008; Macintyre, Ellaway, & Cummins, 2002), appear to operate at different scales; different spatial units of analysis should be used to operationalise both contexts.

Study objectives

The objectives of the study are twofold. First, using purposefully designed homogeneous zones optimising the spatial distribution of active living potential, we assess and compare variation in walking behaviours between these spatial units and between census tracts. Second, we aim to disentangle the relative influence of area-level active living potential and socioeconomic conditions on walking behaviours using alternative geographies to define both contexts, respectively the purposefully designed zones that are homogeneous along active living potential and census tracts that are homogeneous along socioeconomic conditions.

Methods

Individual data on walking behaviour and socio-demographic characteristics are from a larger project aimed at understanding the environmental determinants of walking among middle-aged and older adults (≥45 years) in Montreal, Canada, an urban centre with 1,812,723 inhabitants. This project was approved by the Research Ethics Committee of the Faculty of Medicine of the Université de Montréal.

Sampling

The complete description of the sampling procedures is published elsewhere (Riva et al., 2008) but summarised in the following paragraphs. Stratified sampling of participants ensued from a random selection of census tracts and of individuals living within these tracts. At the time of data collection in 2005, the Island of Montreal was divided into 27 boroughs and 521 census tracts. Because census tracts were unevenly nested within boroughs (min = 4, max = 48 census tracts per borough), they were categorised based on tertiles of average household income. A random sample of 20% of tracts within each borough strata was selected, which resulted in a final sample of 112 census tracts.

A list of postal codes within selected census tract was established which were then linked to a list of telephone numbers through public telephone records. Participants living in one of the 112 census tracts were randomly contacted by a recognised polling firm between February and May 2005 and recruited to participate in a 20-min telephone interview. Only one respondent per household participated; she/he was identified as the next person to celebrate her/his birthday. There were four eligibility criteria: (1) being aged 45 years or older (verified by asking respondents’ their birth year); (2) living in one of the 112 census tracts as confirmed by the verification of the 6 digit postal code; (3) having lived at the current address for at least one year; and (4) being able to respond to the telephone survey in either French or English.

A sample of 2923 (response rate = 29.8%) participated in the survey. The response rate was commensurate with current survey response rates which range between 22 and 48 percent (Galea & Tracy, 2007; Kempf & Remington, 2007). Socioeconomic characteristics of individuals from our sample were correlated to that of populations living in the 112 census tracts suggesting that, despite the response rate of 30%, the sample of individuals obtained for each census tracts are closely aligned to the population living in these census tracts.

Individual measures

Walking—Walking was assessed using questions from the International Physical Activity Questionnaire, a 7-item questionnaire with good test-retest reliability ($r = 0.80$) and moderate convergent validity ($r = 0.30$) with accelerometer-yielded data (Craig et al., 2003). Respondents indicated on how many days they walked for any motive (e.g., walking to get around, to maintain health) for at least 10 min at a time in the previous 7 days. Those who walked on at least one day were asked to estimate the amount of time per day spent walking. Additional questions addressed walking for recreational purposes, i.e. to maintain health/ fitness; respondents were asked to estimate the number of days and typical duration. Total weekly minutes of walking for any motive and for recreational purposes were computed by multiplying number of minutes walked per day by the number of days of walking. We created a residual walking variable, walking for utilitarian purposes, defined by subtracting the total weekly minutes of recreational walking from that of walking for any motive. Although it would have been ideal to address a set of questions specifically on utilitarian walking in the telephone interview, pilot testing showed that such questioning over the telephone was unwieldy and resulted in participant confusion.

From these variables, three dependent variables were computed: the number of 10-minute episodes of walking for any motive, for recreational reasons, and for utilitarian purposes as obtained by dividing by 10 the total weekly minutes of walking for the three motives. These measures were selected in line with public health recommendations that the daily goals of achieving enough physical activity to accrue health benefits can be attained by accumulating bouts of 10 min of moderate physical activity throughout the day (Haskell et al., 2007; USDHHS, 1996).

Individual socio-demographic characteristics—Potential individual socio-demographic confounders accounted for were sex, age, and educational attainment from which dummy variables were created. Age was computed from participants' reported birth year and re-categorized as between 45 and 54 years, 55 and 64 years, or 65 years and older. Participants reported their highest academic degree: less than high school, high school diploma, trade diploma or college diploma, and university degree completed.

Active living potential: measures and design of spatial units

Zones that are homogeneous along ALP were designed to maximise between-area variation in this exposure while minimising within-area variation. The 3-step approach for zone design is fully described elsewhere (Riva et al., 2008). The method is here summarised and illustrated in Fig. 1. Active living potential was measured using three indicators identified as correlates of walking in many studies set across different geographic settings: population density, land use mix, and geographic accessibility to proximity services (Saelens & Handy, 2008; TRB & IOM, 2005).

First, values for the three indicators of ALP were computed at the dissemination area-level (DAs; $n = 3206$) using ArcGIS 9.2 (ESRI, 2006). DAs were used as building blocks to create zones as they are relatively stable geographic units composed of one or more neighbouring street blocks, with a population of 400–700 persons. DAs are the smallest standard geographic area for which all census data are available (Statistics Canada, 2003). Population density was computed by the total population per square kilometer of land area. Land use mix was computed using an entropy index (Frank, Schmid, Sallis, Chapman, & Saelens, 2005; Theil, 1972; Theil & Finezza, 1971) measuring diversity of a component, e.g. land use, within a spatial unit. Geographical accessibility (hereafter accessibility) to selected proximity services, i.e. to supermarkets, banks, pharmacies, and libraries, was defined by the number of these services within a one kilometre network buffer (radius delimited by the road network) computed from the centroid of census blocks comprised within any one DA (this was done to minimise aggregation errors); values were averaged to the DA-level.

Second, we used K-means statistical clustering to categorise DAs into one of seven "categories of exposure". The aim of this step was to group DAs with similar values of population density, land use mix, and accessibility to services into a number of optimal clusters, i.e. "categories of exposure", that are internally homogeneous but different among them. For K-means clustering, the number of clusters (k) must be determined at the onset of analyses; as we had no a priori for such number, we conducted analyses for $k = 4$ to $k = 20$. The 3206 DAs were optimally classified into seven distinct homogeneous categories of exposure corresponding to seven different levels of active living potential, as indicated by peaks (Milligan & Cooper, 1985) in both the Pseudo-F statistic (Calinski & Harabasz, 1974) and the Cubic clustering criterion (SAS Institute Inc., 1998). These seven clusters explained 72.8% of the total variation in the three indicators of ALP. Thus, differences among the seven clusters and similarity of DAs comprised within the same cluster, i.e. within-cluster homogeneity, were both maximized.

Finally, the seven categories of exposure were mapped into ArcGIS 9.2, leading to the delineation of 898 homogeneous zones characterised by one of the seven categories of exposure. Zones are of irregular size and shape; for our study, this was not a problem given that the aim of the zone design was to maximise homogeneity in the exposure of interest.

The seven categories of exposure encompassed more suburban to more central urban types of environments defined by different values for population density, land use mix, and accessibility to services; the categories of exposure are described in Fig. 2. Zones characterised by more suburban contexts were on average larger and had relatively smaller population counts than central urban zones. Low-density and mid-density suburban areas are characterised by the lower values for population density and accessibility to services, whereas diverse central urban areas and central urban areas with very good accessibility are the more densely populated and have greater access to services than any other categories of exposure. The categories of exposure are ordered from what appear as lower potential for active living, i.e. low-density suburban zone, to greatest active living potential, i.e. central urban areas with very good accessibility. For analyses, the categories of exposure were modelled as dummy variables; low-density suburban zone was the reference category.

Socioeconomic context: spatial units and measure

Socioeconomic context was defined using census tracts which are small, relatively stable spatial units with population ranging between 2500 and 8000 and located within large cities with an urban core of ≥50,000 residents; when created, census tracts are as homogeneous as possible in terms of socioeconomic characteristics, e.g. similar economic status and social living conditions (Statistics Canada, 2003). Proportion of people with a university education, as obtained from the 2001 Canadian census (Statistics Canada, 2001), was used to measure the socioeconomic condition of census tracts as they are most homogeneous along this indicator in comparison to other socioeconomic indicators, e.g. proportion of low-income households (Riva et al., 2008).

The sample of 112 census tracts was categorised in tertiles from which dummy variables were created. We contrasted lower and higher tertiles of proportion of university graduates to the middle tertile in light of contrasting results reported in the scientific literature about the association between walking and area-level socioeconomic conditions.

Statistical analyses

Data were analysed using multilevel models with Poisson sampling model and the log link function for count data with constant exposure (for every resident of an area, the exposure is the same) and adjusted to account for overdispersion (under the Poisson model, the variance and the mean of the outcome variable are expected to be equal; in our data, variance was greater than the mean). Analyses were conducted using HLM version 6.04 (Raudenbush, Bryk, & Congdon, 2005).

Two sets of analyses were conducted. First, using unconditional two-level models, we assess and compare how walking behaviours vary between the purposefully designed zones and between census tracts. This allows for describing the extent to which zones capture the area-level variation in ALP shown to be associated with walking. Second, to disentangle the relative influence of ALP and socioeconomic position, data were analysed using cross-classified multilevel models.

In our sample, over 80% of zones straddled more that one census tracts (results reported elsewhere; Riva et al., 2008), indicating that one zone which is homogeneous in ALP can be characterised by different socioeconomic conditions. Hence, zones and census tracts datasets are not nested within one another (not hierarchically structured), but are best characterised as overlapping. As a result, we are dealing with a sample of individuals that are cross-classified into overlapping areas, where (i) individuals living in environments similar in terms of ALP are exposed to different socioeconomic conditions, (ii) individuals living within the same socioeconomic environment are exposed to environments with different levels of active living potential, or (iii) individuals living within the same socioeconomic environment are exposed to the same level of active living potential. Cross-classified multilevel analyses are better suited to the structure of these spatially parameterised datasets (Raudenbush & Bryk, 2002). The cross-classified structure of the data set is presented in Table 1, and shows that for any level of active living potential, residents can be exposed to different socioeconomic contexts. Since walking behaviours could plausibly be influenced by both ALP and socioeconomic contexts, assessing their independent and joint effects is pertinent.

The modelling procedures for the cross-classified analyses followed a step-up approach (Raudenbush & Bryk, 2002). Unconditional models were first performed to partition variance in the number of 10-minute walking episodes between individuals and between level-2 units (variation between zones + variation between census tracts). Variation between level-2 units was further partitioned to that attributable to differences between zones and to differences between census tracts. Associations between walking and active living potential and socioeconomic position were estimated from successive models. The final model adjusts for individuals' characteristics. Strength of associations between ALP and socioeconomic position and the number of 10-minute episodes of walking are estimated by event rate ratios (ERR) and 95% confidence intervals (95% CIs).

Results

Description of individual, zone, and census tract samples

After listwise deletion due to incomplete or missing responses on walking behaviour, age, and educational attainment, and extreme outlier values on walking, data from 2716 (92.9%) participants were analysed. The individual sample included 1678 women (61.8%) and 1038 men (38.2%). Individuals aged between 45 and 54 years accounted for 28.7% of the sample, those 55–64 years for 34.7% whereas individuals aged 65 years and older represented 36.6%. About one third of the sample had completed university (31.4%) whereas 23.2% did not complete high school. Individuals reporting at least one 10-minute episode of walking in the previous week walked on average 29 episodes (median = 17) for any motive ($n = 2301$), 27 episodes (median = 12) for utilitarian purposes ($n = 1577$), and 23 episodes (median = 15) for recreational reasons ($n = 1183$).

Individuals were successfully geocoded within one of 270 zones (30.1% of the total 898 zones) using their six-digit postal codes and match up files. On average there were 10 individuals per zone (median 6; standard deviation: 12.4); 43.0% of zones comprised less than five individuals. In zones including five or more individuals, the proportion of individuals with annual household income below $20,000, with less than high school education, and with university education were correlated at 0.57 ($p < 0.01$), 0.61 ($p < 0.01$), and 0.72 ($p < 0.01$) respectively with corresponding indicators obtained from Statistics Canada generated for each zone, suggesting that the sample of individuals within-areas was similar to characteristics of populations living in these zones. Individuals were further cross-classified within 112 census tracts, with an average within-tract sample of 24 individuals (median 27; standard deviation: 6.2).

On average zones were larger than census tracts (1.28 km^2 versus 0.82 km^2), but this difference was not statistically significant ($t = 0.78$; $p = 0.438$). Zones and census tracts were similar in average population counts (3903 individuals in zones versus 3715 in census tracts; $t = 0.304$; $p = 0.761$). There was greater variability between zones in area size ($F = 3.64$; $p = 0.057$) and population counts ($F = 29.61$; $p < 0.001$) than between census tracts.

Assessing variation in walking behaviours across zones and across census tracts: results of two-level models

Results of variation in walking behaviours across zones and across census tracts are shown is Table 2. Although variation in utilitarian walking was statistically significantly ($p < 0.05$) across zones and across census tracts, variations were larger between zones: 3.19% of the variation in utilitarian walking was attributable to differences between zones and 1.75% to differences between census tracts. Overall predictive probability and plausible value ranges indicate that whereas, on average, people reported 16 episodes of utilitarian walking per week, these episodes varied between 7 and 35 across zones and between 8 and 29 across census tracts. There was significant but small variation in walking for any motive across census tracts only. Recreational walking did not vary significantly across zones or census tracts. The small variation in overall walking may arise because zones may better distinguish environments that are conducive to utilitarian walking.

Disentangling the relative influence of active living potential and socioeconomic conditions on walking: results of cross-classified multilevel models

Cross-classified unconditional models partition total variation in walking episodes between individuals and between level-2 units, which is the sum of variation between zones and between census tracts; results are shown is Table 3. Variation in the number of 10-min episodes of walking for any motive and for utilitarian reasons was significant across census tracts only. However, the extent of this variation warrants further attention. As observed in the two-level zone model, a greater proportion of level-2 variation in utilitarian walking was attributable to differences between zones (63.9%) rather than to census tracts (36.1%). The small sample sizes of individuals within zones could explain why variation between zones is not statistically significant in cross-classified models. Again, there was no significant between-area variation for recreational walking.

Results of cross-classified associations between ALP and socioeconomic conditions and 10-min episodes of walking are presented in Table 4. In models adjusting for individuals' characteristics (Model 3), ALP was significantly ($p < 0.05$) associated with walking for utilitarian and recreational motives, and marginally ($p < 0.10$) with walking for any motive. People living in diverse and high accessibility central urban zones respectively cumulated on average 20 episodes (ERR: 1.87; 95% CI: 1.00, 3.47) and 21 episodes of utilitarian walking per week (ERR: 1.92; 95% CI: 1.02, 3.65) compared to 11 episodes in low-density suburban zones. Residents of central urban zones with high accessibility to services reported on average 30 episodes of walking for any motive per week (ERR: 1.42; 95% CI: 0.97, 2.09) compared to 21 episodes among residents of low-density suburban zones. In contrast, residents of diverse central urban zones were less likely to walk for recreational purposes in comparison to residents of low-density suburban zones (ERR: 0.65; 95% CI: 0.43, 0.99). A greater proportion of university graduates in the census tract was significantly associated with more episodes of walking for any motive (ERR: 1.25; 95% CI: 1.06, 1.49), and for utilitarian (ERR: 1.33; 95% CI: 1.04, 1.71), and recreational (ERR: 1.24; 95% CI: 1.01, 1.54) purposes.

Discussion

Using purposefully designed homogeneous zones optimising the spatial distribution of an exposure shown to be associated with a health indicator, i.e. the active living potential of small areas and walking behaviours, this study (1) examined if variation in walking behaviours are greater across areas that maximises within-area homogeneity and between-area heterogeneity in ALP than across standard administrative units; and (2) disentangled the relative influence of area-level ALP and socioeconomic conditions onwalking behaviours using alternative geographies to define both contexts. These objectives were pursued in light of previous research showing that census tracts may not be appropriate spatial units for measuring ALP of residential environments which, we argue, could lead to measurement errors and (non-differential) misclassification of this exposure therefore limiting the soundness of the estimation of its effects on walking behaviours (Riva et al., 2008).

Our findings show that, only for utilitarian walking, there was a significantly greater variability in the number of episodes of walking across zones homogeneous along ALP indicators than across census tracts. Indeed, 3.19% of the total variation in utilitarian walking can be attributable to differences between zones, compared to 1.75% for census tracts. Yet zones did not maximise variation in total or recreational walking. In line with other studies (Frank et al., 2003), this suggests that specific attributes of the built environment have a differential influence on walking motives; zones maximising homogeneity along other attributes of the built environment might have yielded stronger and significant variance estimates for recreational walking.

Most studies using multilevel models to analyse inequalities in health across small areas show that the between-area variation in health is often small to modest (roughly between 0.1% and 6%). The 3.19% variance estimate in utilitarian walking across homogeneous areas is thus in line with that observed in other studies, and not greater as could have been expected. Other authors have reported small to moderate estimates of variance when using more homogeneous zones and small differences when comparing these estimate to those obtained from analyses defining small areas using standard administrative units (Haynes et al., 2008; Ross et al., 2004; Stafford et al., 2008). The added value of purposefully designing areas rather than using standard administrative units has indeed been raised, especially so when considering the efforts required for designing zones (Ross et al., 2004; Stafford et al., 2008).

However, other studies have shown that, when measuring direct area effects, "*it does matter where* [we] *draw the boundary*" (Flowerdew et al., 2008). Cockings and Martin (2005) and Flowerdew et al. (2008) reported stronger associations between deprivation and limiting long-term illness in zones designed to be of consistent shape and population size in comparison to areas defined using census boundaries. Haynes et al. (2008) reported slightly stronger area effects on accident risks among children in areas designed to be homogeneous along social and economic characteristics and in smaller, more local areas. In our study, homogeneous areas were defined by the interplay of population density, land use mix, and accessibility to services in creating distinct environmental contexts. As a consequence, we could not directly compare results of associations between walking and the categories of exposure to that of associations with census tract indicators of ALP. However using cross-classified multilevel models allowed for the estimation of the distinct influence of ALP and socioeconomic conditions on walking behaviours. Results showed that when exposure is operationalised by more appropriate area units, i.e. zones homogeneous along exposure of interest, both ALP and socioeconomic conditions are significantly associated with walking for any, utilitarian, and recreational motives.

Higher levels of ALP were significantly associated with more episodes of utilitarian walking and walking for any motive (yet only marginally so the latter), but with less episodes of recreational walking. These findings support those of other studies reporting increased levels of utilitarian walking in areas characterised by high population density, more mixed land-use, proximity to services (Saelens & Handy, 2008; TRB & IOM, 2005), and more ‘walkable’ environments (Frank et al., 2005). These results again draw attention to the specificity of built environment contexts for influencing different motives for walking. Diverse central urban zones conducive to more episodes of utilitarian walking were less conducive to recreational walking than low-density suburban zones. Recreational walking may be influenced by other environmental features not examined in this study, such as accessibility to public open spaces and parks, safety from traffic and crime, and aesthetics of the surroundings (Saelens & Handy, 2008).

The socioeconomic context of small areas was also associated with walking, whereby greater educational attainment in the census tract was associated with more episodes of walking for any, utilitarian and recreational motives. These findings are not fully aligned with that of other studies reporting less walking in more deprived areas (Gordon-Larsen et al., 2005; Rutt & Coleman, 2005) and contradict others reporting more walking in more deprived areas (Fisher et al., 2004; Giles-Corti & Donovan, 2002; Miles et al., 2008; Ross, 2000). The discrepancies likely result from the choice of different indicators for measuring socioeconomic conditions which, although linked, may be tapping into different dimensions of the social and material context of areas. More research is needed to unravel the extent of inequalities in walking behaviours across areas of different socioeconomic contexts as measured by different indicators.

Elsewhere, we have shown that the spatial distribution of ALP and socioeconomic indicators differed, therefore providing an empirical (and conceptual) justification for using different spatial units for defining these two contexts (Riva et al., 2008). In cross-classified multilevel models, the influence of the built and socioeconomic environments on walking, although measured simultaneously, was measured independently from one another; the colinearity between the two exposures being therefore limited. It is possible that the socioeconomic conditions and ALP of an area are associated, but this association is complex and certainly not linear (Macintyre, 2007). Going back to Table 1, of all the respondents living in areas with the most potential for active living, i.e. diverse and high accessibility central urban zones, 27.7% lived in areas with lower socioeconomic position whereas 35.8% lived in areas with higher socioeconomic position. This shows that associations between socioeconomic conditions and built environment features are not the same across the setting of the study. Measuring both exposures in the same administrative spatial unit within which homogeneity of socioeconomic conditions is more likely, may bias estimation of area effects on health.

Methodological considerations

Interpretation of results is subject to limitations due to sampling procedures and statistical power. A representative sample of respondents was randomly selected within the 112 census tracts. Zones were designed independently of this sampling. Small individual sample sizes in zones may influence estimation of effect sizes. Ideally, homogeneous zones should be defined at the onset of a study and participants sampled within homogeneous and contrasting zones. The cross-sectional design of the study prevents from ascertaining whether characteristics of the built and social environments were the catalyst for walking or whether persons involved in greater amounts of walking chose to live in environments with greater potential for active living. Longitudinal studies, wherein change over time in both individual walking behaviours and environments, are warranted. Other limitations of the study have to do with self-reported minutes of walking and disentangling recreational and utilitarian walking. Replication studies are required to further assess the value of designing zones relevant to other health indicators and other ecological exposures.

Conclusion

In health and place research, areas are most often conceptualised as an ecological level of influence exerting a similar influence on the health of the local population. Within this epidemiological conceptualisation, we argued that establishing the homogeneity of small areas in relation to ecologic exposures is a major methodological consideration as it is likely to minimise measurement error of exposures and non-differential exposure misclassification. We showed that, although small, variation in utilitarian walking was more important across purposefully defined areas maximising homogeneity of active living potential, than across census tracts. In addition, using alternative boundary definition to operationalise ALP and socioeconomic context, results of cross-classified multilevel analyses showed that both exposures are independently associated with walking behaviours. Yet, it is possible that standard administrative units are appropriate definition of small areas for some health indicators and some ecologic exposures, but this must be established prior to conducting analyses (Flowerdew et al., 2008). For public health, the relevance of designing homogeneous zones lies in their design which allows for the optimal identification of environmental determinants of a given health indicator in order to inform interventions aiming at creating supportive environments for health. It also draws attention to the need to inventory and investigate different area attributes potentially influencing health as part of the surveillance function of public health.

Yet, other epidemiological conceptualisations about the links between place and health are likely to produce different, though complementary, results. For example, some authors have proposed to create bespoke areas around individuals' residential location (Chaix, Merlo, Subramanian, Lynch, & Chauvin, 2005; Propper, Jones, Bolster, Burgess, Johnston, & Sarker, 2005) using computerised techniques; some authors have applied this to explore the influence of the built environment on walking (Berke, Koepsell, Vernez Moudon, Hoskins, & Larson, 2007; Nagel, Carlson, Bosworth, & Michael, 2008). As these bespoke areas are unique to each individual, this approach conceptualises places as having a distinct influence on the health of each individual. Other authors argue for the adoption of a more 'relational' approach in health and place research, i.e. one that considers the interrelation and interaction between individuals and their settings and for more complex accounts of health outcomes produced from these interactions (Cummins, Curtis, Diez-Roux, & Macintyre, 2007; Gatrell, 2005). The added value of each of these theoretical and empirical approaches for understanding how place relates to health remains to be established and should be the focus of further investigations.

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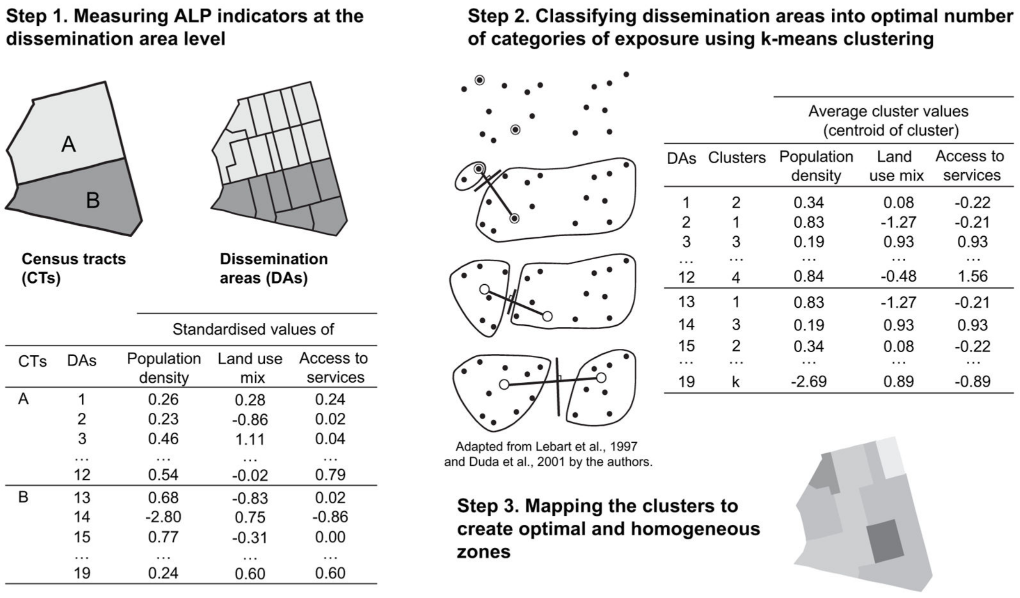

Step 1. Measuring ALP indicators at the dissemination area level

CTs	DAs	Standardised values of Population density	Land use mix	Access to services
A	1	0.26	0.28	0.24
	2	0.23	-0.86	0.02
	3	0.46	1.11	0.04
	…	…	…	…
	12	0.54	-0.02	0.79
B	13	0.68	-0.83	0.02
	14	-2.80	0.75	-0.86
	15	0.77	-0.31	0.00
	…	…	…	…
	19	0.24	0.60	0.60

Step 2. Classifying dissemination areas into optimal number of categories of exposure using k-means clustering

DAs	Clusters	Average cluster values (centroid of cluster) Population density	Land use mix	Access to services
1	2	0.34	0.08	-0.22
2	1	0.83	-1.27	-0.21
3	3	0.19	0.93	0.93
…	…	…	…	…
12	4	0.84	-0.48	1.56
13	1	0.83	-1.27	-0.21
14	3	0.19	0.93	0.93
15	2	0.34	0.08	-0.22
…	…	…	…	…
19	k	-2.69	0.89	-0.89

Adapted from Lebart et al., 1997 and Duda et al., 2001 by the authors.

Step 3. Mapping the clusters to create optimal and homogeneous zones

Fig. 1.

Steps in designing zones homogeneous in active living potential.

Description of categories of exposure

			Zones N (%)	Number of DAs Mean (SD)	Area in km^2 (%)
A	Low-density suburban	Suburban areas characterised by lowest population density, land use mix, diversity, and low accessibility to services.	31 (3.5)	4.6 (8.2)	222.2 (45.5)
B	Middle-density suburban	Suburban areas characterised by low population density, homogeneity of land use, and weak accessibility to services.	104 (11.6)	4.5 (8.6)	75.2 (15.4)
C	Suburban/ urban axial	Suburban and urban areas characterised by low population, density, diverse land uses, and weak accessibility to services. Located close to main street axis.	146 (16.3)	3.5 (5.4)	83.7 (17.1)
D	Mix urban/ suburban	Suburban and urban areas with average values of population density, land use mix, and accessibility to services. Located mainly in the central and eastern part of the island.	243 (27.1)	2.9 (3.5)	41.0 (8.4)
E	Urban residential	Urban areas with high population density, land use homogeneity, and weak accessibility to services. Located mainly in residential areas peripheral to central urban areas.	212 (23.6)	2.2 (2.6)	17.1 (3.5)
F	Diverse central urban	Urban areas characterised by average population density, land use diversity, and good accessibility to services.	85 (9.5)	5.3 (8.8)	32.6 (6.7)
G	Central urban with high accessibility	Urban areas with high population density, land use homogeneity and highest accessibility to services. Located mainly in central areas of the Island of Montréal.	77 (8.6)	6.0 (15.7)	16.5 (3.4)
			898 (100.0)	**3.6 (7.1)**	**488.3 (100.0)**

Fig. 2.

Zones and categories of exposure.

Table 1

Cross-classification of 2716 individuals in 270 zones with different active living potential levels and 112 census tracts with different proportions of university graduates.

	Category differentiating proportion of university graduates in census tract			
Categories of exposure in zones	**Lower tertile**	**Middle tertile**	**Higher tertile**	**Total**
Low-density suburban	60	25	25	110
Middle-density suburban	25	168	193	386
Suburban/urban axial	179	159	179	517
Mix urban/suburban	275	173	103	551
Urban residential	168	96	26	290
Diverse central urban	155	173	176	504
Central urban with high accessibility	84	141	133	358
Total	946	935	835	2716

Table 2

Unconditional two-level multilevel model estimates of between zones and between census tracts variance in the number of 10-minute episodes of walking among 2716 residents of Montreal, Canada.

Variance partitioning	**Walking for any motive**	**Utilitarian walking**	**Recreational walking**
Zone model			
Estimated variance			
Between individuals	3.12	5.13	5.29
Between zones	0.0002 (ns)[a]	0.169 ($p < 0.01$)	0.006 (ns)
% Variation attributable to zones	0.01	3.19	0.11
Census tract model			
Estimated variance			
Between individuals	3.12	5.56	5.31
Between census tracts	0.0003 ($p < 0.05$)	0.099 ($p < 0.01$)	0.004 (ns)
% Variation attributable to census tracts	0.01	1.75	0.08

[a] ns, Non-significant.

Table 3

Unconditional cross-classified multilevel model estimates of between level-2 units variance in the number of 10-minute episodes of walking among 2716 residents of Montreal, Canada.

Variance partitioning	**Walking for any motive**	**Utilitarian walking**	**Recreational walking**
Estimated variance			
Between individuals	2.79	4.89	5.21
Between zones	0.016 (ns)[a]	0.121 (ns)	0.005 (ns)
Between census tracts	0.031 ($p < 0.05$)	0.068 ($p < 0.05$)	0.006 (ns)
% Variation attributable to level-2 units (zones and census tracts)	1.66	3.72	0.21
% Variation across level-2 units attributable to zones	34.04	64.02	45.45
% Variation across level-2 units attributable to census tracts	65.96	35.98	54.55

[a] ns, Non-significant.

Table 4

Cross-classified multilevel models predicting the number of 10-minute episodes of walking as a function of active living and socioeconomic area exposures among 2716 residents of Montreal, Canada.

	Model 1[a]	**Model 2**[b]	**Model 3**[c]
	ERR (95% CI)[d]	**ERR (95% CI)**	**ERR (95% CI)**
Walking for any motive			
Categories of exposure in zones			
Low-density suburban	1.00	1.00	1.00
Middle-density suburban	1.03 (0.69, 1.53)	0.98 (0.66, 1.46)	0.97 (0.65, 1.44)
Suburban/urban axial	0.94 (0.64, 1.39)	0.93 (0.63, 1.36)	0.95 (0.65, 1.39)
Mix urban/suburban	1.03 (0.71, 1.52)	1.04 (0.71, 1.52)	1.07 (0.73, 1.55)
Urban residential	0.93 (0.61, 1.40)	0.95 (0.63, 1.43)	0.97 (0.65, 1.46)
Diverse central urban	1.19 (0.81, 1.75)	1.16 (0.80, 1.70)	1.22 (0.84, 1.78)
Central urban with high accessibility	1.42 (0.96, 2.11) *	1.37 (0.93, 2.02)	1.42 (0.97, 2.09) *
Proportion of university graduates in census tracts			
Lower tertile		1.01 (0.84, 1.20)	1.02 (0.86, 1.21)
Middle tertile		1.00	1.00
Higher tertile		1.23 (1.04, 1.46) **	1.25 (1.06, 1.49) **
Utilitarian walking			
Categories of exposure in zones			
Low-density suburban	1.00	1.00	1.00
Middle-density suburban	1.27 (0.66, 2.45)	1.23 (0.65, 2.36)	1.16 (0.61, 2.22)
Suburban/urban axial	1.14 (0.60, 2.16)	1.14 (0.61, 2.14)	1.14 (0.61, 2.13)
Mix urban/suburban	1.35 (0.72, 2.54)	1.38 (0.75, 2.58)	1.39 (0.75, 2.57)
Urban residential	1.17 (0.60, 2.28)	1.21 (0.63, 2.35)	1.20 (0.62, 2.31)
Diverse central urban	1.80 (0.96, 3.38) *	1.77 (0.95, 3.30) *	1.87 (1.00, 3.47) **
Central urban with high accessibility	1.98 (1.03, 3.78) **	1.91 (1.01, 3.61) **	1.92 (1.02, 3.65) **
Proportion of university graduates in census tracts			
Lower tertile		1.03 (0.80, 1.34)	1.06 (0.82, 1.36)
Middle tertile		1.00	1.00
Higher tertile		1.30 (1.01, 1.68) **	1.33 (1.04, 1.71) **
Recreational walking			
Categories of exposure in zones			
Low-density suburban	1.00	1.00	1.00
Middle-density suburban	0.78 (0.51, 1.21)	0.73 (0.47, 1.13)	0.75 (0.49, 1.16)
Suburban/urban axial	0.77 (0.50, 1.17)	0.74 (0.49, 1.13)	0.75 (0.50, 1.13)
Mix urban/suburban	0.76 (0.50, 1.15)	0.76 (0.50, 1.15)	0.78 (0.52, 1.17)
Urban residential	0.70 (0.44, 1.11)	0.72 (0.45, 1.14)	0.76 (0.49, 1.19)
Diverse central urban	0.66 (0.43, 1.01) *	0.64 (0.41, 0.98) **	0.65 (0.43, 0.99) **
Central urban with high accessibility	0.86 (0.55, 1.33)	0.82 (0.53, 1.27)	0.86 (0.56, 1.31)
Proportion of university graduates in census tracts			

	Model 1[a]	**Model 2**[b]	**Model 3**[c]
	ERR (95% CI)[d]	**ERR (95% CI)**	**ERR (95% CI)**
Lower tertile		0.95 (0.77, 1.19)	0.95 (0.77, 1.18)
Middle tertile		1.00	1.00
Higher tertile		1.20 (0.97, 1.49) *	1.24 (1.01, 1.54) **

* $p < 0.10$;

** $p < 0.05$.

[a] Model 1: associations between active living potential and walking.

[b] Model 2: associations between active living potential, area-level socioeconomic position, and walking.

[c] Model 3: Model 2 adjusted for individual characteristics.

[d] ERR (95%CI): event rate ratio and 95% confidence intervals.